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AEROSPACE SYSTEMS AND TECHNOLOGY - THE ROLE OF RAE

by

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SUMMARY

After a brief summary of the history of RAE an outline is given of the Establishment's facilities, including the guided weapon ranges which are currently being modernised. The scope and rationale of its research programme are illustrated by descriptions of a number of specific items: night and all-weather operations, flight control of ASTOVL aircraft, applications of computational fluid dynamics to aircraft and gas turbines, advanced airframe materials, aim-point refinement for guided weapons, and remote sensing of the Earth's surface from space. The use of assessment techniques in research planning and in support of the definition of operational requirements is then discussed and reference is made also to relationships with industry and to future trends in research. (JES)

Departmental Reference: DR/55/07

Text of Handley Page Memorial Lecture given to the Royal Aeronautical Society at Hamilton place, London on 21 April, 1988.

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1 INTRODUCTION

I feel very honoured at being invited to provide the 1988 Handley Page Memorial Lecture. As I only met Sir Frederick once, at a dinner at Imperial College during my student days, I cannot introduce my lecture with personal recollections of this great pioneer of British aeronautics. I believe however that he would have agreed with my sentiment that, in the spirit of the pioneers of aviation, it is better to concentrate in a commemorative lecture on recent advances and new opportunities in aerospace rather than to linger on the achievements of the past.

The Society has specifically asked me to focus my lecture on the Establishment of which I have the privilege to be Director. I welcome this request since it provides a timely opportunity not only to discuss its programmes and achievements but also to give an up-to-date account of its relationships with industry and within the Government sector. By way of introduction I will touch briefly on the historical evolution of the Establishment; I will then discuss in turn its role, facilities and programmes, concluding with a few observations regarding the future.

2 EVOLUTION

The RAE has its origins in the Balloon Factory, operated by the Army, which moved to the Laffan's Plain site at Farnborough in 1905. It was there that Samuel Cody made in 1908 the first controlled flight of a powered aircraft recorded in the United Kingdom (Fig 1). Although the work was funded by the Army there were considerable doubts at that time in military circles as to whether aircraft had a worthwhile role to play in warfare. Attitudes had however changed radically by the outbreak of the First World War, a conflict in which manned aircraft were for the first time to play an important role.

By 1914 the Balloon Factory had become the Royal Aircraft Factory which designed and built in quantity aircraft used by the Royal Flying Corps, including in particular the highly successful SE5 (Fig 2); a total

of no less than 5205 of these was built at various factories in the United Kingdom. Tensions inevitably arose at that time because Farnborough was both designing aircraft in competition with private industry and fulfilling a regulatory role regarding the latter's products. As a consequence a decision was taken in 1916 that Farnborough should cease to design aircraft and become a research, development and regulatory organisation. In due course its title became the Royal Aircraft Establishment and the pattern was set for its subsequent role and function. Since then design and construction work at RAE has been limited to research and trials equipment with the exception of a few bursts of activity to fill gaps when private industry was unable to meet an urgent requirement and when the capability to do so existed within the Establishment.

In its early days RAE was concerned predominantly with what might be described as the basic disciplines of aeronautics - aerodynamics, structures and structural materials, flight mechanics and propulsion; vigorous and productive dialogues took place then, and have continued ever since with designers and design teams in industry, interaction in the 1920s with Handley Page on leading-edge slotted flaps being an interesting early example[1]. The scope of the Establishment's programmes has broadened steadily over the years not only to embrace guided weapons and space systems but also to reflect the increased importance of avionics and overall systems integration in aircraft design. Current developments in sensors, solid state electronics, computing techniques, displays, fibre optics and direct voice input will contribute strongly to further advances in avionic systems and will lead to improved operational effectiveness, reduced pilot workload and improved maintainability.

The RAE has expanded over the years to occupy a number of separate sites in addition to its main base at Farnborough. These include:

(a) RAE Bedford which includes a large airfield, well equipped for R&D flying, a flight simulator complex and a major wind tunnels site;

(b) Ranges for guided weapons development trials at Aberporth (supported by the Llanbedr airfield), West Freugh and Larkhill (shared with the Royal Artillery);

(c) The sites at Pyestock, West Drayton and Cobham which prior to April 1983 constituted the National Gas Turbine Establishment; the latter two sites are concerned with Naval engineering;

(d) Satellite ground stations at Oakhanger and Lasham.

3 THE ROLE OF RAE TODAY

Over its long history the RAE has been the responsibility of several different government departments. Military applications of aerospace technology have however been a consistent theme with the level of involvement in civil programmes varying widelv depending on the circumstances. Notable civil work has included the investigation in the 1950s of the loss of Comet aircraft and the associated research in metal fatigue, and more recently an extensive involvement in the development of Concorde. Today the RAE is contained within the Procurement Executive of the Ministry of Defence. Its primary role is to provide the impartial source of technological expertise and assessment capability which is necessary to enable the Ministry to obtain aerospace equipments - aircraft, helicopters, guided weapons and satellites - which meet its needs economically, dependably and safely; the Establishment's programme and capability reflect not only the requirements of this role in the short term but also the breadth of forward-looking research necessary to guide the Ministry in deciding how best to exploit, and where necessary stimulate, technological advances which have the potential to reduce the cost of meeting the evolving threat. A proportion of the Establishment's programme is funded by the Department of Trade and Industry for research related specifically to civil aircraft and space systems and as a contribution towards the cost of technology research of applicability to both civil and defence applications. RAE also manages on behalf of both MOD and DTI, programmes of extramural research at the Universities and in industry.

While RAE is the lead Research Establishment within MOD on aerospace technology its programme is closely coordinated with related work in other MOD Research Establishments. The Royal Signals and Radar Establishment at Malvern, for example, has primary responsibility for airborne radar and for various sensors which RAE, in association with industry, is exploiting in avionic systems and in target seekers for guided weapons.

4 MAJOR FACILITIES

While the technological expertise and intellectual capability of the staff are the most important resources in meeting the Establishment's primary objectives, mention must also be made of the wide range of major facilities for which RAE is responsible; these constitute a substantial National capability of importance in both defence and civil aerospace. It would be neither practicable nor desirable to catalogue these in this paper. I would however like to mention a few of the more important capabilities.

(a) Engine test facility

The engine test facility at Pyestock (Fig 3) provides a facility unique in Europe in which modern gas turbine powerplants for both civil and military aircraft can be operated in test cells in which their complete altitude, temperature and speed range can be represented; icing effects can also be included. An adjacent noise facility, which includes a very large anechoic chamber, enables the effect of forward speed on jet noise to be investigated using models at a scale large enough for acoustic studies to be mounted on jet mixing phenomena associated with the propulsive jets of civil aircraft.

(b) Wind tunnels

RAE operates a comprehensive suite of wind tunnels covering the speed range up to Mach 12. I will mention only two. Firstly the 8ft subsonic/supersonic Wind Tunnel at RAE Bedford shown in Fig 4. This pressurised facility is used extensively in the testing of both civil and military aircraft; it played a major role in the Tornado programme and will do so again for EFA. Secondly the 5m pressurised low speed Wind Tunnel at Farnborough. This too

is used in the development testing of both civil and military aircraft. It has been used extensively in tests on the Airbus series of aircraft (Fig 5); a notable capability of this facility is that it enables the airfield and stalling performance of small combat aircaft to be studied under full-scale conditions, ie at full scale Mach number and Reynolds numbers simultaneously. Helicopter aerodynamics also feature in the tunnel's programme including work on stores carriage.

(c) Flight simulators

The flight simulators operated by RAE fall into two categories. Firstly, there is a suite of simulators at Farnborough concerned with the representation of air-to-air and air-to-ground combat. In these the emphasis is on the mission and a relatively simple representation is used of the aircraft performance characteristics and cockpit. This installation is complemented by a simulator complex at Bedford where the emphasis is on the flight dynamics and handling characteristics of the aircraft; this complex, which has recently been rebuilt, now possesses a high fidelity moving base motion capability which is currently being commissioned. This performance enhancement is particularly important in representing the motion of agile helicopters and the future generation of short take-off and vertical landing aircraft which we hope to see entering service soon after the turn of the century.

(d) Guided weapons and electronic warfare simulation

RAE also has powerful capabilities for the mathematical modelling of guided weapon systems and of electronic warfare systems for the protection of combat aircraft. The philosophy is to provide a mathematical model into which individual hardware components can be incorporated for research and development purposes. Applications in the guided weapons context include research on guidance and homing techniques.

RAE facilities are made available to industry on a repayment basis and British Aerospace and Rolls Royce respectively make considerable use of the wind tunnels and the engine test facility. The wind tunnels are also used to a significant extent by industry from overseas. The Establishment is now taking steps to publicise the availability of its facilities more widely to areas of UK industry with which it does not have regular contact, under the auspices of the DTI sponsored Civil Industrial Access Scheme (CIAS). Currently some 5% of RAE's cash budget is derived from repayment work for industry.

5 WEAPON RANGES

The three weapon test ranges operated by RAE are used primarily for guided weapon development and evaluation trials. A large over-water range is located at Aberporth in Wales while the air-to-surface weapon range at West Freugh near Stranraer in Scotland is now being used also for short range air defence weapons; the Larkhill range on Salisbury Plain provides the land background essential to trials of smart anti-armour weapons and other battlefield systems.

RAE Aberporth (Fig 6) is the largest of the three ranges. Sea targets for anti-ship and air-to-surface weapons are moored in Cardigan Bay, while remotely piloted and towed aerial targets are operated from RAE Llanbedr further up the coast. Extensive instrumentation at the Aberporth rangehead includes air and sea surveillance radars, tracking radars and telemetry and flight termination systems. Optical kinetheodolites are deployed along the coast.

Much of the instrumentation at all three ranges is now reaching the end of its useful working life; some of the kinetheodolites date back to 1940. Capabilities must also be enhanced to cater for the next generation of guided weapons. A major programme of modernisation of range instrumentation and infrastructure is therefore underway.

At Aberporth, most of the existing rangehead instrumentation will be updated and a major new instrumentation site will be established on Mynydd Rhiw, a mountain on the Lleyn Peninsula. This will give low level

coverage and improved accuracy in the northern part of the range and allow full safety monitoring of trials over the whole of the recently extended Range Danger Area (rf horizons are shown in Fig 6). The Mynydd Rhiw facilities will include a new tracking radar, telemetry reception and flight termination transmitters. Improvements will be carried out at West Freugh and Larkhill at the same time. Invitations to tender for the whole Ranges Modernisation Programme are due to be issued shortly.

A contract has already been placed for new electro-optical tracking instruments to replace the ageing kinetheodolites on all three ranges. These new equipments comprise a trailer mounted servo-platform, carrying TV and film cameras, together with a millimetric range-only radar and a mobile control cabin. Each instrument will be capable of providing full 3-D trajectory coverage in real time.

These improvements constitute a comprehensive modernisation of the RAE weapon test range facilities and will ensure their viability well into the next century.

6 RESEARCH PROGRAMME

Having outlined the Establishment's physical assets I would now like to talk about its applied research programme. This is very much geared to meeting requirements foreseen by 'customers' in MOD headquarters and to pursuing research under DTI funding in support of UK industry. Our objective is to plan the work as a coherent whole so that each of the Government Departments providing funding benefits also from the contribution of the other, with particular attention being given to the stimulation of spin-off from defence-funded research to civil applications. Rather than catalogue a vast range of individual topics I would like to discuss in turn a few typical but varied examples of the areas of research that are currently being pursued.

6.1 Night and all-weather operations

Important areas of work at RAE relate to the operation of combat aircraft at night and in poor weather conditions. After some initial work a few years ago on low light television it was decided that thermal imagers sensitive to infra-red radiation provided the best basis for

a system to enable a pilot to both fly and identify targets in the dark. Important advances were being made at the Royal Signals and Radar Establishment in the relevant sensor technology and these were embodied in the 'Class II common module' equipment produced by GEC under MOD contract for exploitation in a wide range of defence applications. RAE in collaboration with GEC has developed a system in which an infra-red picture generated by such a sensor is seen by the pilot in his head-up display, super-imposed on the scene ahead. This equipment, which is known as a forward-looking infra-red (FLIR) sensor, provides a high resolution forward view and is particularly good for showing up targets such as tanks.

The head-up display provides only a relatively small porthole of vision which is supplemented in this system by the pilot wearing night vision goggles (Fig 7) which are sensitive to the near-IR wavelengths prevalent in starlight and moonlight. Trials in Hunter, Buccaneer, Tornado and Harrier have demonstrated that the combination of the FLIR and the night vision goggles enables normal daylight flying techniques to be used at night.

Obvious difficulties with such a system are that

(a) the goggles do not possess the depth of focus necessary to enable the outside world and cockpit instruments to be encompassed without re-focussing, and

(b) the goggles are readily dazzled by cockpit lighting.

These difficulties have been overcome by arranging for the pilot to view his instruments beneath the goggles with the cockpit illuminated at a wavelength to which the goggles are insensitive.

RAE and GEC Avionics received jointly in 1987 the Queen's Award for Technological Achievement for this work which has already led to export successes and which is the basis for the system currently under development for use in Harrier GR5 and its US counterpart the AV8B.

Despite the many advantages of this system it has nevertheless some limitations:

(i) Power cables and masts are not always seen in good time;

(ii) Ridge lines are not always readily discernable in poor conditions;

(iii) Heavy precipitation causes significant image deterioration;

(iv) There is no forward vision through clouds.

To overcome these disadvantages, trials are now being carried out to investigate the principle of augmenting the FLIR display with selected outputs from a digital map and terrain-referenced navigation system (Fig 8). Power cables, pylons, and ridge lines stored in the map can be called up and presented on the head-up display in true perspective, overlaying the FLIR picture, thus delineating clearly the obstacles ahead in advance of their acquisition by the FLIR. In rain and cloud, the aircraft can be flown for periods on these obstacle and ridge-line displays until improving conditions allow the FLIR to re-assert itself.

An obvious question to ask is how these new techniques compare with the automatic terrain following system incorporated in the Tornado GR1 which uses radar to scan the terrain in front of the aircraft, giving it some capability to operate at zero visibility. A problem with this approach is that an enemy may be able to detect the radar at long range, thus providing him with an opportunity to alert his defences and jam the system. As a result attention here too is now being given to the exploitation of terrain referenced navigation (TRN), harnessing the map data base to compute the terrain profile in front of the aircraft. The technique is amenable to expansion into terrain avoidance where, for tactical reasons, the pilot can choose to fly around rather than across hills, obstacles and enemy defences. This is a subject of continuing research by RAE in collaboration with Industry. The main deficiency of TRN as an automatic terrain following system is that errors in the data base could result in the aircraft colliding with uncharted obstacles. This problem increases the lower the aircraft is expected to fly, since smaller obstacles which are less likely to have been captured in the cultural data base then pose a hazard. One solution being developed by RAE is to supplement the TRN with a CO_2 laser, which is able to detect such obstacles but is itself difficult to detect and to jam. This laser

is also eye safe and therefore makes peace-time training possible. Future work includes the de elopment of a CO2 laser with a higher pulse repetition frequency capable of detecting very small obstacles and cables.

6.2 Flight Control Systems for ASTOVL aircraft

A US/UK Memorandum of Understanding relating to Advanced Short Take-Off and Vertical Landing (ASTOVL) aircraft was signed in January 1986. Under this the two countries are jointly assessing design studies of supersonic STOVL aircraft based on four specific propulsion concepts (Fig 9) and are also exchanging research data on wide ranging aspects of ASTOVL technology. The aim is to bring the technology base in both countries to a point where development of a demonstrator aircraft could be initiated. RAE is playing a major part in the UK contribution to the programme.

An important facet of the STOVL propulsion concepts under consideration is the need for close integration of the propulsion control system with the flight control system during the transition from wing-borne to jet-borne flight. This is necessary because of potential discontinuities in thrust and thrust moments during such transitions associated with all of these complex propulsion systems. In the UK the RAE identified the need for integrated control research on ASTOVL aircraft some 10 years ago and launched a programme with the acronym VAAC (Vectored thrust Aircraft Advanced flight Control). This is a programme of research into control laws, displays and inceptors (cockpit controls) for ASTOVL aircraft. The objective is to develop concepts, and design and assessment techniques, through mathematical studies, ground-based piloted simulation, and flight in a research Harrier. The work aims to provide a sound basis for the design of ASTOVL aircraft, freeing candidate configurations from some of the traditional stability and control constraints; in this way operational effectiveness can be maximized throughout the flight envelope.

Compared with conventional aircraft, STOVL configurations have an additional degree of freedom since, whatever their physical arrangement, the direction of the overall thrust can in some way be varied during transition between wing-borne and jet-borne flight. They also operate down to zero velocity. In addition, supersonic ASTOVL designs have relatively complex propulsion control systems which may require up to five or six

control inputs instead of the Harrier's two (throttle position and nozzle angle). These features present unique challenges and opportunities for the control system designer.

The performance of any aircraft control system depends ultimately on the interaction between the system and the pilot. Here ASTOVL is especially demanding. Particular concerns are not only to provide carefree handling in all phases of flight - from wing-borne, through transition, to hover - but also to ensure that the pilot's task is made as simple as possible and his workload kept within reasonable bounds. For some 10 years UK industry and RAE have been making piloted simulator studies of control strategies and laws, both on a conceptual basis and for specific ASTOVL designs. The overall control law strategy and design question is being tackled in depth under VAAC, the RAE's combined flight and simulation programme.

VAAC makes use of the advanced moving base simulator now being commissioned at Bedford to which I referred earlier. This provides powerful real-time computing and systems capabilities supplying sound, visual and motion cues to the pilot. In particular the large displacement motion system has been designed to provide the powerful kinaesthetic cues needed when studying highly dynamic aircraft responses. The most attractive control strategies developed on the simulator are now being taken through to flight. For this purpose a two-seater Harrier at Bedford has been fitted with a fly-by-wire system in the rear cockpit, which will permit a wide range of control laws to be studied safely. Although the research aircraft is a Harrier its programme will provide information relevant to other ASTOVL configurations.

6.3 Computational fluid dynamics (CFD)

RAE continues to play a key role in the development of techniques for the calculation of airflow around aircraft and weapons and through their powerplants. Programmes mounted in collaboration with the Aircraft Research Association and with British Aerospace and Rolls Royce have led to the development of practical techniques for use in design exploiting potential flow techniques coupled with local representation of boundary layers and flow separation; the work has included careful comparison

with wind tunnel and test cell data to ensure that the numerical results are accurate and meaningful. The use of these computational techniques has played an important part in the development of successful civil and military hardware. Indeed their development and application was an important element in the work which led to Aerodynamics Department RAE receiving this year a Queen's Award for Technological Achievement, jointly with British Aerospace, for its contribution to the design of the Airbus A320 wing.

In the external flow context, attention is now being turned to the solution of the exact Euler equation for inviscid flow about practical shapes and important progress has been made in developing techniques which reduce substantially the heavy computational task involved. These further developments should in due course lead to the evolution of practical techniques for the calculation of the airflow about aerospace vehicles using the Navier-Stokes equations with viscous terms included; such advances are important in improving our ability to evaluate the performance of civil aircraft more accurately and to enable us for the first time to model satisfactorily the flow about combat aircraft and missiles at the limits of the flight envelope. As an example of the kind of results now being obtained during technique development, Fig 10 shows a computer-generated image of the flow past the tip of a swept wing at a Mach number of 0.84 and an incidence of 3.06°. Note the strong cross-flow associated with the tip vortex. Local Mach numbers over the wing here exceed 2. The numerical simulation includes an accurate representation of the wing-tip geometry and a computational grid that is specially matched to both the geometry and the expected flow structure. These are new developments prior to which the flow pattern, and consequently the spanwise loading, was significantly misrepresented in the vicinity of the tip.

An important internal flow application of CFD is the design of aerofoil shapes for compressor and turbine blades in engines. Methods based on the numerical solution of the inviscid potential flow equations have been used to design turbine blades for over 25 years. Until recently, it has not however been possible to design transonic compressor blades

by computer. This is because the boundary layer on the suction surface of a transonic fan blade is subjected to a strong adverse pressure gradient, and, in many cases, shock waves. It is therefore quite thick and close to separation if not actually separated. The inclusion of boundary layers in the calculation is therefore essential. However, the boundary layers change the passage shape to such an extent that the computation tends to become unstable.

An inviscid-viscous interaction method has been devised at RAE Pyestock which overcomes the instability, and a computer program has been evolved which successfully predicts this complex transonic flow. Figure 11 shows the predicted Mach number contours in two adjacent passages of a typical transonic fan such as is used in a large civil engine. The leading-edge shock wave can be seen, and the quite thick boundary layer or wake. The RAE program has been used to tailor the aerofoil shape so as to control the shock pattern and minimise boundary layer and separation losses. The loss associated with this particular profile was in fact nearly halved (Fig 11).

In order to prove and demonstrate this method, RAE designed new rotor blade profiles for an existing Rolls-Royce civil fan. The new rotor was made and tested at model scale by Rolls-Royce under MOD contract. It achieved its design performance on the first test. The design point efficiency was over 3% higher than the rotor it replaced, corresponding to a reduction in loss of 30%. The method is now widely used by Rolls-Royce. When applied to a military fan, it enabled a performance shortfall to be diagnosed; the first stage rotor redesigned using the method increased design speed flow and efficiency by 4%.

This is a good example of how industry and RAE working closely together can reduce the time and cost of equipment development. It is believed that the RAE method retains a lead in this particular application of CFD as a design method. There remains, nevertheless, scope for major enhancement: an important and very challenging next step will be to adapt the method to handle conditions approaching blade stall.

6.4 Airframe materials

RAE has long played a major role in the development of advanced airframe materials[2] with increased specific strength and stiffness and with a well-balanced combination of the various other properties which are important from the fabrication and airworthiness viewpoints. Leaving on one side the important story of the development of carbon fibre, I would like to say a few words first about aluminium-lithium alloys.

A programme of alloy development to reduce the density of structural aluminium alloys was started at RAE in 1978. The target was a 10% reduction in density while at the same time matching the engineering properties of the currently used 2000 and 7000 series alloys, thus achieving a useful increase in specific properties. A Royal Aircraft Establishment patented Al-Li-Mg-Cu alloy which meets these requirements, designated 8090, resulted from this work. It is now being produced in commercial quantities under licence by British Alcan at their dedicated Kitts Green plant and is being evaluated by industry in the UK, Europe and the USA. The alloy has flown on EAP and in the United States on the McDonnell Douglas F15 STOL demonstrator aircraft. Although lithium containing aluminium alloys will cost more than the 2000 and 7000 series alloys they replace, the equipment used in the manufacture of components in the latter alloys is also suitable for the fabrication of aluminium-lithium alloy components. Thus the capital cost of introducing these new alloys into aircraft construction will be relatively small. The mass saving more than compensates moreover for the increased material cost in aerospace applications. Materials and Structures Department RAE, jointly with British Alcan, have received this year a Queen's Award for Technological Achievement for the development of this alloy.

Vapour deposited alloys

The slow cooling rates associated with the large volumes of metal used in conventional ingot metallurgy processes result in equilibrium phases being achieved in the microstructure; consequently only limited

amounts of binary, ternary and quaternary additives can be introduced into solution in an aluminium lattice. By increasing the rate of solidification it is possible both to refine the microstructure and to increase the amount of alloying additions that can be retained in solid solution, thus giving increases in strength and modulus and the possibility of further reductions in density if low density alloying additions can be made.

A number of processes have been developed in the US and UK which involve the very rapid cooling of liquid metal at rates greater than 10^5 $^{o}C/s$ to produce particulate, ribbon or fibre. Microstructures of these products are unique and incapable of production by conventional ingot metallurgy. The finely divided materials thus produced must however be recombined to produce a bulk product with the risk that the heating, compaction and working required to do this will destroy these unique microstructures and properties.

At RAE an alternative approach is being pursued in which bulk material is produced directly by a high rate vapour deposition process. In this process advantage is taken of the atom by atom quenching from the vapour phase to circumvent both the limitations of ingot metallurgy and the difficulty of recombining particulate material.

In the RAE vapour deposition process a temperature controlled collector oscillates over the evaporation source. The deposit builds at the rate of 6 mm per hour and deposits of up to 44 mm in thickness have been produced (Fig 12).

Alloy development with this process has concentrated on the Al-Cr-Fe system. The chromium content in solid solution can be increased to more than 14% by vapour deposition. This compares with less than 0.4% for conventional melting and casting techniques. Apart from room temperature strength and modulus, which are higher than those of currently used aluminium alloys, the elevated temperature stability of Al-Cr-Fe alloys is significantly better (Fig 13). Deposits of this alloy can

moreover be readily rolled to sheet, and extrusion and forging parameters are being explored to permit the production of net or near-net shapes. The elevated temperature properties are such that the alloy can be considered for components operating at temperatures up to 250°C, ie some 130°C above the temperature at which the Concorde alloy is considered satisfactory for long-term service.

The Al-Cr-Fe alloy system is only one of many alloys that could be produced by co-evaporation from a single source and an even wider range is possible by mixing vapour from separate sources. The exploration of alternative compositions which is now proceeding at RAE could lead to alloys with even better thermal stability, which will be able to operate at the lower end of the temperature range now occupied by titanium alloys, with significant mass savings.

Metal matrix composites

Metal matrix composites for use in airframe and missile applications are another important area of current study. These materials offer combinations of strength and stiffness which can be tailored through variations in matrix composition, reinforcement (fibre, whisker or particulate) and fabrication sequence.

Potential matrix materials for airframe and missile applications include aluminium, magnesium and titanium with reinforcing fibre/whiskers of boron, silicon carbide, carbon or alumina; high modulus particles of materials such as silicon carbide constitute an alternative form of reinforcement. Particulate reinforced material is attractive in that near-isotropic properties are obtained and it is amenable to conventional fabrication processes such as rolling, extrusion and forging. The unidirectional strength and stiffness of continuous fibre reinforced materials are considerably greater than those of particulate reinforced material but the properties are highly anisotropic. Both types of materials have potential applications; the continuous fibre reinforced material for stringers and struts and the particulate/whisker reinforced material for sheet, extrusions and forgings.

RAE is currently exploring liquid metal infiltration, metal spraying and powder routes to a range of metal matrix composites. Much of this work is in collaboration with industry and the results will provide an indication of the potential of these materials in terms of properties, of quality and of the ability to achieve adequate dimensional tolerances.

6.5 Weapon aim-point refinement

The size of warhead required in a guided weapon depends very much on how near it can be placed to the most vulnerable point of the target. Indeed, if a hit can be achieved in the right place no warhead may be needed; the kinetic energy of the missile alone may be sufficient to do the required damage. Given that suitable data are available from the sensor, selecting the right aim-point should be possible using a rule-based expert system. I should like to illustrate that approach by showing the results of some work for air-to-air weapons, which has been undertaken at the RAE. Short-range air-to-air weapons have traditionally been infrared guided and recent developments which allow cheap imaging systems to be built are likely to result in that tradition continuing. The difference will be, however, that while the early missiles could not guarantee a hit and so had to be equipped with large warheads and proximity fuzes, the next generation, which will have an image of reasonable quality available within the seeker, will be able to make a precise selection of an aimpoint; smaller, lighter and potentially cheaper missiles should therefore be feasible.

Figure 14 illustrates the aiming problem associated with infrared homing missiles. This shows an infra-red image of a Tornado with full afterburner in operation. As you can see, the plume is by far the brightest and largest feature in the image so that merely aiming for the centre of the projected area would almost certainly result in a miss. An answer to that particular problem would be to aim forward of the hot area; the image of a Harrier in Fig 15 illustrates, however, that the hottest areas are sometimes within the airframe and that the simple rule to aim forward could cause a miss in those instances.

By using the temperature measuring capability of an imaging seeker, it is possible to determine the thermal contours of the target and from the temperature data deduce what is airframe and what is plume. Further, by examining salient features of the image in a quantitative manner, its orientation can be determined. The results of these processes are illustrated in Fig 16. The expert system has correctly identified the plume and the nose of the target. For a real weapon, the best aim-points for likely targets would have to be determined by vulnerability studies but to allow the image processing work to proceed, the cockpit was selected as the aim-point in all cases, partly because most people have an idea where the cockpit is likely to be, and hence the correctness of the computer assessment can be easily judged, and secondly, because if the position of the principal parts of the aircraft can be identified, the position of any other aim-point can be calculated easily. In this, I should stress that we are not trying to recognise the cockpit but having determined the principal features of the target, have calculated where the cockpit is likely to be. The technique has been tested against several hundred images and has been found to be very robust.

Figure 17 corresponds to the Harrier image shown in Fig 15. It is interesting in that the expert system has detected symmetry of heat and has postulated the position of engines. In fact Harrier has only one engine but the main engine exhaust does emerge symmetrically in two areas marked.

As part of the operation of the expert system, various checks are involved which include such items as determining that the point selected for the cockpit is in a part of the airframe which is large enough to incorporate it. If these checking tests fail, a second attempt, using a different route through the rules, is made. If that attempt also fails, the aimpoint reverts to the centre of the projected area. The system thus has a good fall-back position and to illustrate that, my final illustration (Fig 18) in this section is of a very different type of air vehicle. For this image, the expert system is able to determine at once that the image is not that of an aircraft and selects the centre of the projected area as the best that it is able to do.

6.6 Remote sensing

The programme examples that I have given so far have been biassed towards aircraft and guided weapon applications. RAE is however, active also in the space scene where its programme includes work on satellite technology, satellite system integration and use of satellites in remote sensing of the Earth. Much of this activity is integrated into the programmes led by the British National Space Centre, including the work on remote sensing, to which I will limit my comments.

The RAE has a long history of work on remote sensing starting with photography from balloons and kites and moving on through aircraft platforms to space-based systems. The work on satellite remote sensing started in 1977 when the RAE ground station at Oakhanger was modified to handle data from the US Seasat oceanographic sensing satellite, and processing facilities were set up at Farnborough to convert the raw radar returns into imagery.

Many of the existing satellite remote sensing systems use passive sensors which collect reflected sunlight and emitted radiation from the Earth, but can only be used in the absence of cloud. Much recent research has therefore concentrated on active space radar systems which have an all-weather day-and-night imaging capability.

The remote sensing research programme at RAE is aimed at establishing a better understanding of imaging mechanisms so that useful information can be extracted from satellite data and exploited for both civil and military applications. At present the main thrust of the programme is to develop near real-time applications of imaging radar data. This involves the provision of fast processors for generating imagery and extracting feature information. The results of this work will be demonstrated using radar data from the ESA ERS-1 satellite which is scheduled for launch in 1990. To give an example of the standard now being achieved by remote sensing data, Fig 19 shows a synthetic aperture radar image of a bulk carrier in the English Channel; the data is from Seasat but the production of this image utilised powerful signal processing techniques developed at RAE.

The growing interest in applications of satellite imagery led to the formation of the National Remote Sensing Centre at RAE in April 1980. The Centre provides imagery, processing and analysis facilities and expert advice to enable industry, government and academia to evaluate the potential benefits which can be derived from the use of satellite data. The objective of the Centre is to help build-up a UK industrial capability so that British firms can win a greater share of the developing world market for remote sensing products and services. Its capabilities will be increased substantially by the addition of a new data centre for use in the first instance in processing data from the ERS-1 satellite. This new equipment, which is being funded by the Department of Trade and Industry through the British National Space Centre, complements a new data receiving terminal which is to be built at RAE West Freugh.

6.7 Systems assessment

It is often an expensive process, involving the dedicated effort of scarce skilled staff, to pursue applied research programmes and to take them through a subsequent demonstrator phase to the point where the results can be exploited in an aerospace project without introducing an unacceptable level of risk. It is important therefore to concentrate limited resources on those areas of work where the potential benefits are large. In the case of civil aircraft the basic objective can often be defined relatively easily; operating cost is for example closely related to drag, mass, specific fuel consumption and easy maintainability. The criteria are, however, more complex in defence systems where it is often not easy to identify a single measure of merit at a subsystem level. For example, to meet future requirements in air combat one needs to make judgements based on a knowledge of the relative benefits of investing in improvements to the aircraft or to the weapons that it carries.

RAE is involved in studies in this field aimed both at guiding the deployment of research resources and at providing an input into MOD debates on what levels of performance should be sought in new equipment.

By way of example I would like to say a few words about close-turning air-to-air combat when the combatants are armed with short range missiles with infra-red seekers. For simplicity I will concentrate mainly on combat between two solitary aircraft but studies have also been done in more complex scenarios.

Aircraft turn rate is a dominant factor in classic close combat. Figure 20 shows how this parameter is bounded by lift, g and power limits. The outcomes of several thousand combat simulations using a mathematical model known as PACAM have been shown to correlate well with an Air Combat Parameter (ACP*) defined as the square of the product of maximum attained and sustained turn rates, which is in effect a measure of aircraft agility.

In Fig 21 the ordinate represents a measure of effectiveness defined as the ratio of weapons launched by the aircraft to the total number launched by the aircraft and its opponent and the abscissa indicates the value of ACP*. The curve provides therefore an indication of the effect of aircraft capability in combat against a specific opponent. Parity is achieved at an ACP* ratio of unity and a margin of 20-40% to the right of the ordinate is usually deemed sufficient to ensure success. The graph shows good correlation both with the computer model and with results from combat in a manned simulator. Similar curves can be produced relating to multiple combat but these tend to be flatter due to the probability of chance encounters.

In establishing the performance parameters for a combat aircraft, attention must of course also be given to beyond visual range combat and the use of medium range missiles with radar guidance. Studies at RAE which have brought together the modelling of short and beyond visual range combat, and which have led to specific recommendations regarding performance needs, have played an important part in the debate within MOD on the operational requirements for EFA. Such studies must, however, be interpreted with care since they are inevitably based on radical simplifications of the operating scenario; their reliability does moreover depend on the quality and reliability of the available evidence gleaned from operational trials and combat simulation on the ground.

7 THE FUTURE

The foregoing examples will I hope have given you a feel for the range of technologies being pursued at RAE which is of crucial importance to the satisfaction of the anticipated future needs of MOD and which provides also a wide range of technology which UK industry can exploit

in the international market place. The Establishment's programmes are defined in consultation not only with its Government-sector customers but also with senior representatives of the aerospace industry. Our objective will continue to be to mount cost-effective programmes in partnership with industry so that the results of work relevant to industry's and MOD's needs can be transferred rapidly and efficiently into the design and development of aerospace systems. The broad scope of the Establishment's programmes is reflected in the recent change of title from Royal Aircraft Establishment to Royal Aerospace Establishment.

In a time of severe constraint on resources the RAE programme has to be focussed strongly on those rapidly-developing areas which are likely to have a major impact on future generations of aerospace equipment. All the areas of technology highlighted in this paper fall within this category. Future programme development is likely to result in increased attention being given to the application of intelligent knowledge-based systems to the avionics of military aircraft and in the guided weapons context to target acquisition, aimpoint refinement and the countering of electronic countermeasures. Work on combat aircraft will include further study of possible configurations for supersonic STOVL aircraft and the reduction of the radar and infra-red signature of aircraft and weapons will also be an important subject for study.

The multidisciplinary environment of RAE with no vested interest in which solution is adopted when comparing disparate means of meeting the demands of MOD or the market place, provides a stimulating and effective environment for pursuing these important issues. The proposed Defence Research Agency, if implemented, may well introduce new flexibilities into RAE operations in a strong customer-contractor environment. The Establishment has the strength and vitality to flourish in such a scenario.

In conclusion, I would like to thank sincerely my various colleagues who have provided material for this lecture. At the same time I should make it clear that I personally take responsibility for the opinions expressed. I should, however, emphasise that these represent my personal perspective and do not necessarily reflect the official views of the Ministry of Defence.

REFERENCES

No	Author	Title etc
1	C H Barnes	Handley Page aircraft since 1907 Putnam, London (1976) p210 et seq
2	G G Pope	Structural materials in aeronautics: prospects and perspectives Aerospace, 13, 4, 16-22; 5, 22-30 (1986)

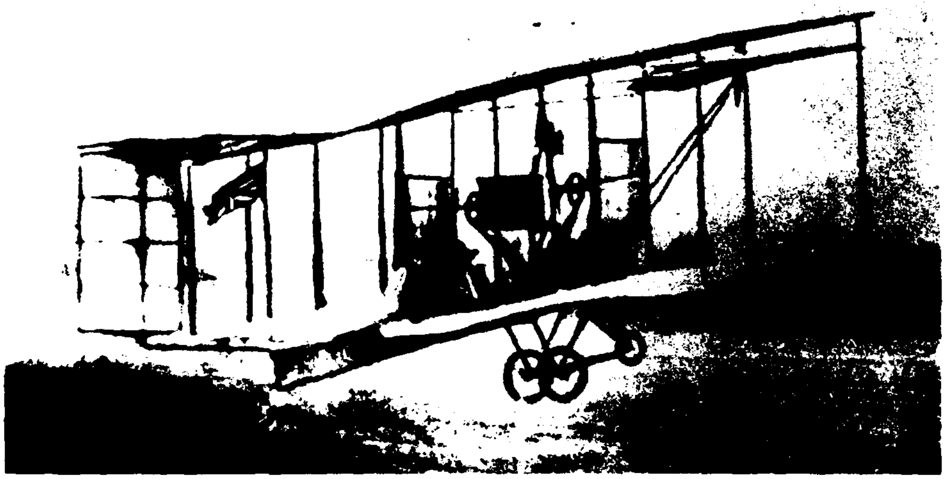


Fig 1 Cody's army aeroplane No.1

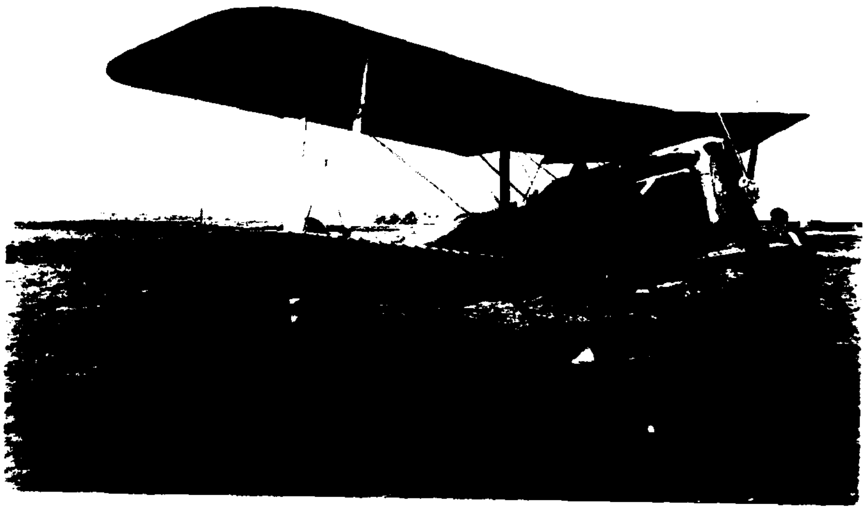


Fig 2 An SE5 at Farnborough in 1916

Figs 3-5

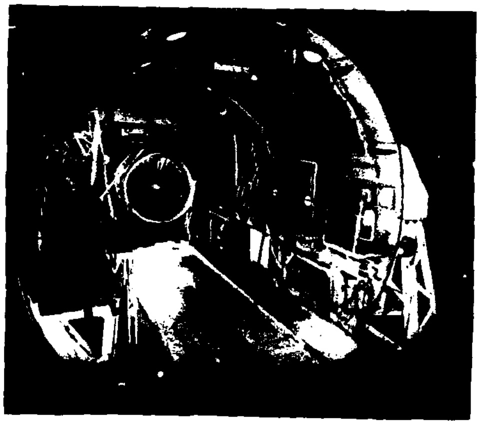


Fig 3 Cell 3 West at Pyestock used for testing civil fan engines

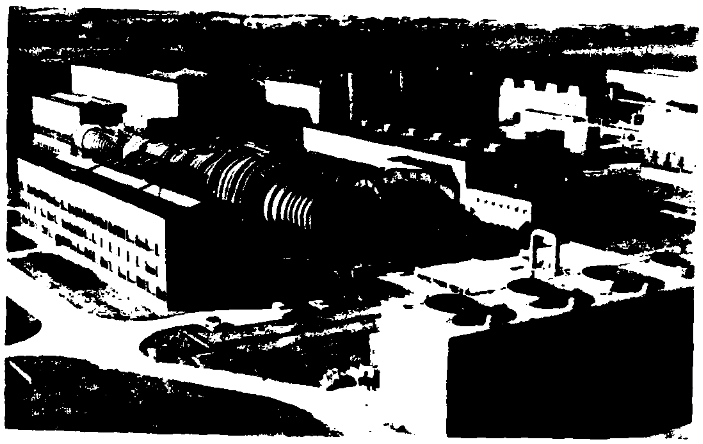


Fig 4 The 8ft subsonic/supersonic wind tunnel at Bedford

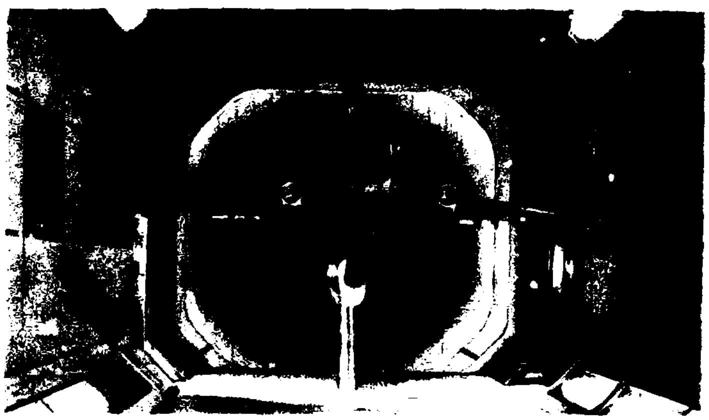


Fig 5 Model of the A300 B Airbus in the 5m wind tunnel at Farnborough

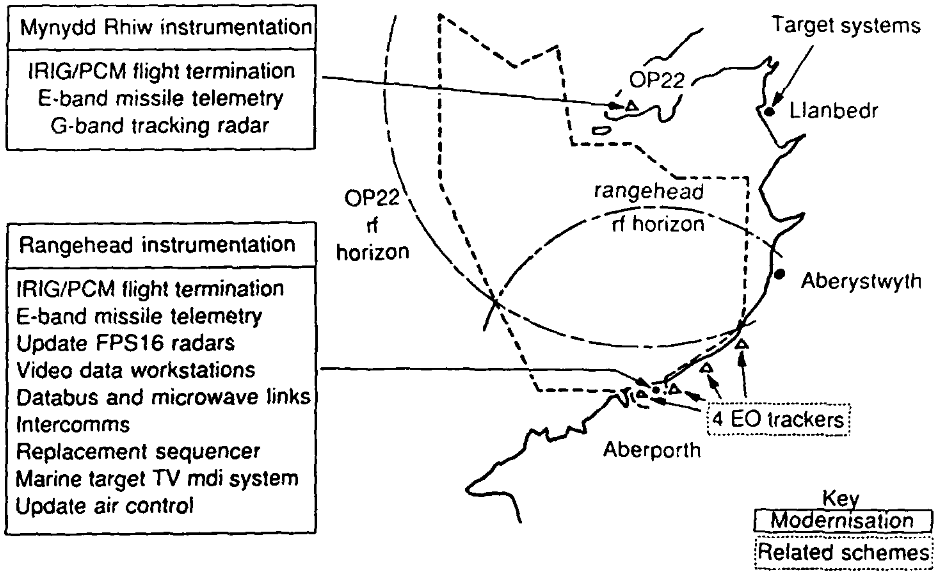
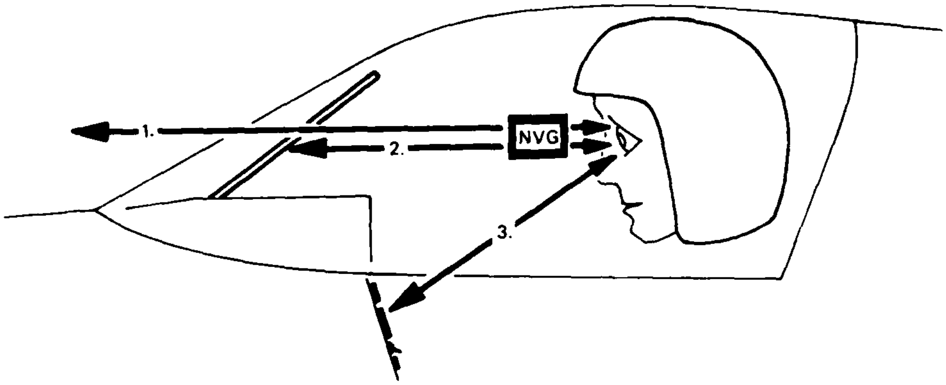


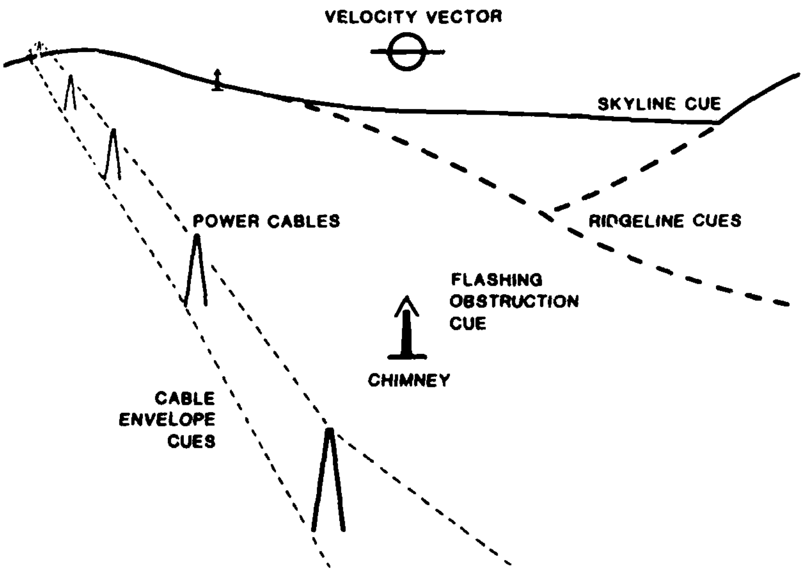
Fig 6 Modernisation of the guided weapons range at Aberporth

Figs 7&8



1. OUTSIDE WORLD VIEWED THROUGH THE GOGGLES
2. FLIR IMAGE ON HUD VIEWED THROUGH THE GOGGLES
3. INSTRUMENTS VIEWED ROUND THE GOGGLES

Fig 7 Night vision system for combat aircraft



TR 88042

Fig 8 Cues from TRN superimposed on FLIR image on head-up display

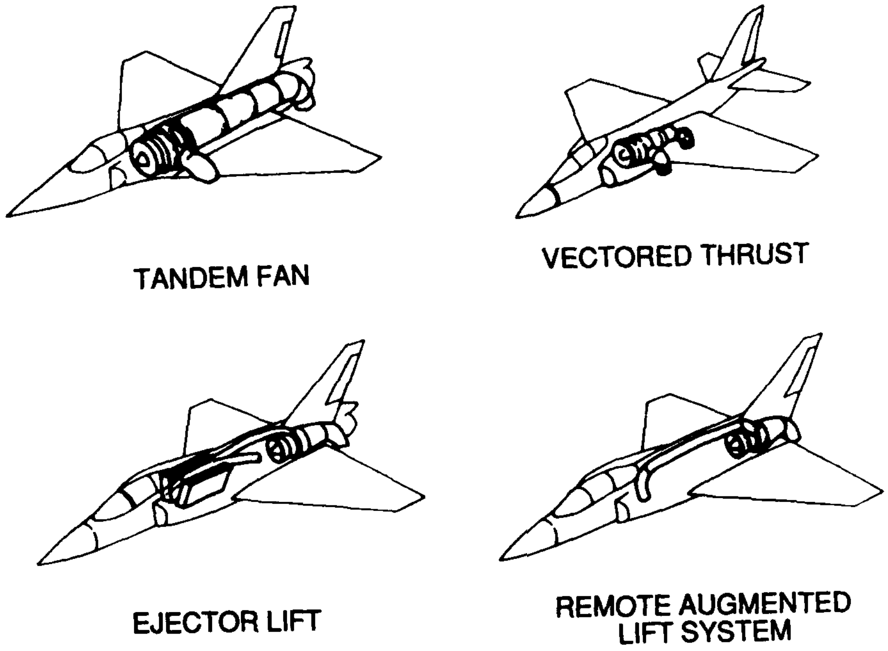
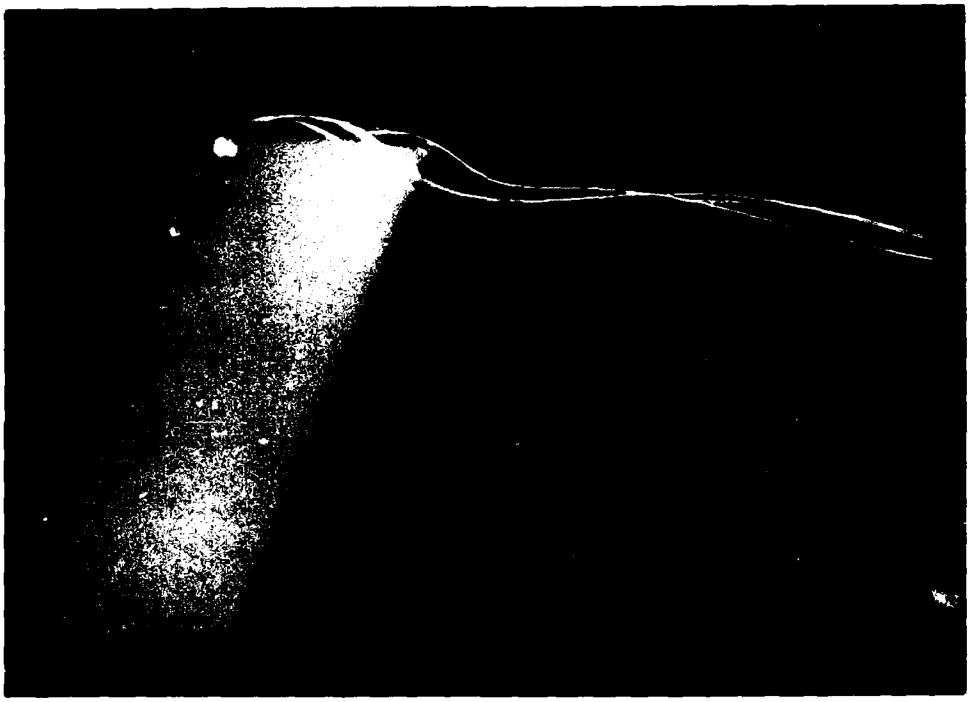


Fig 9 ASTOVL propulsion concepts

Fig 10



TR 88042

Fig 10 Computer-generated image of wing-tip vortex

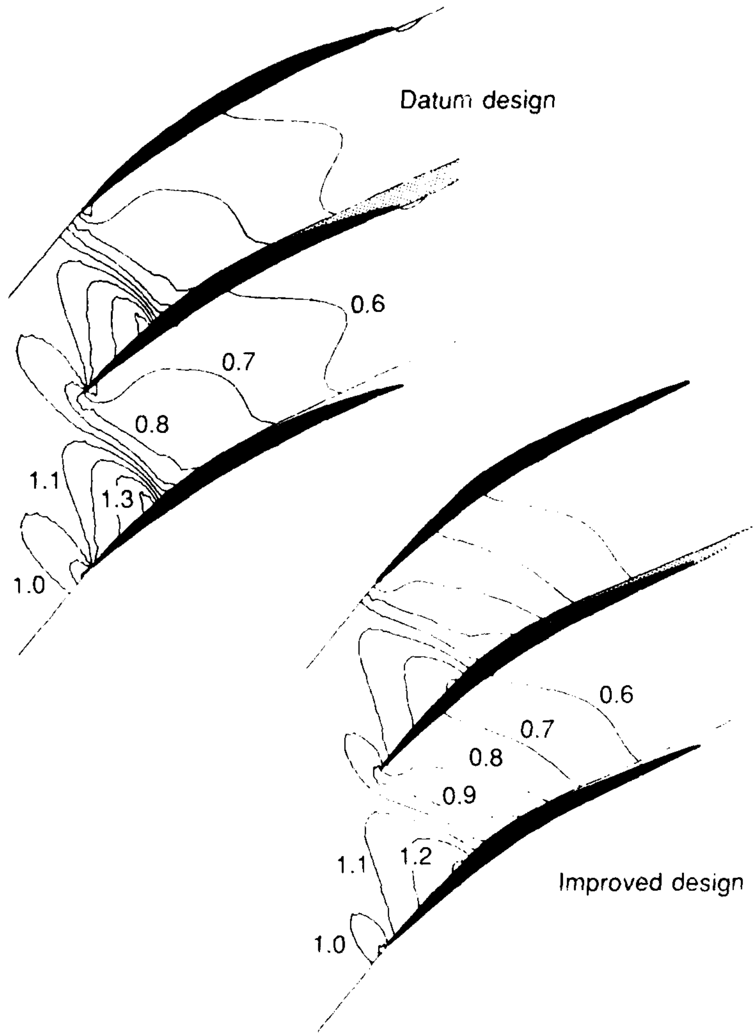


Fig 11 Predicted Mach number contours between blades of transonic fan

Figs 12&13

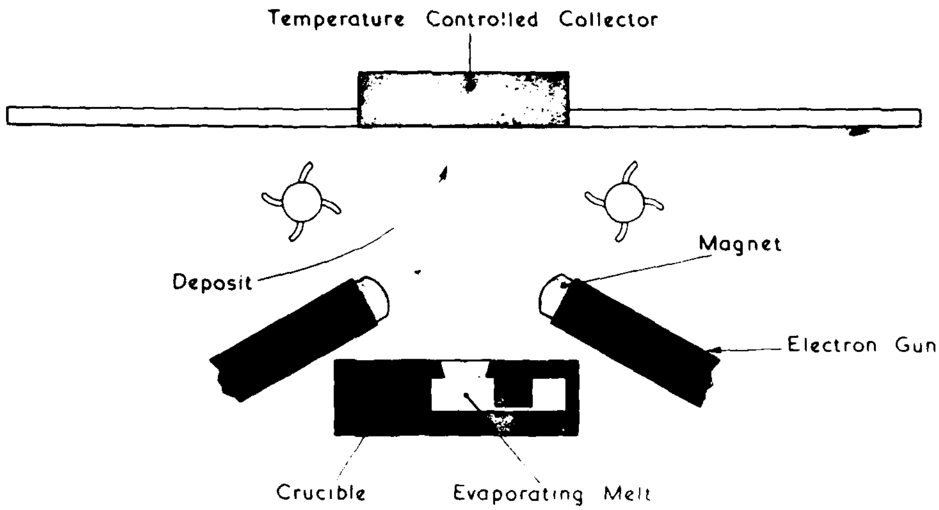


Fig 12 Vapour deposition equipment

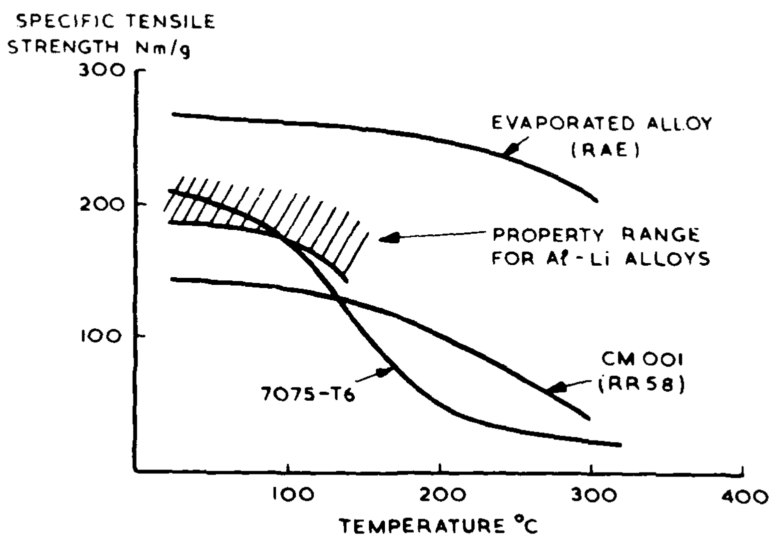


Fig 13 Specific tensile strength of aluminium alloys

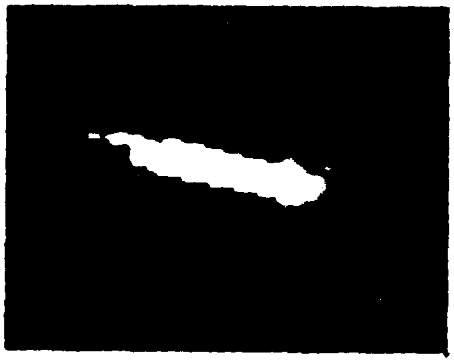


Fig 14 IR image of Tornado with reheat

Fig 15 Tornado image analysis

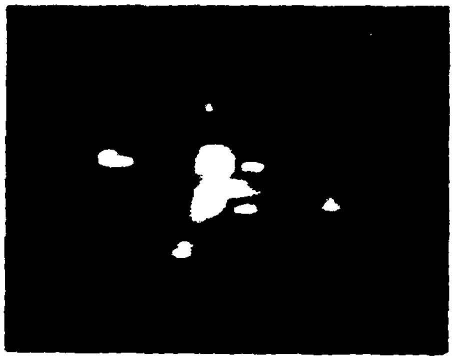


Fig 16 IR image of Harrier

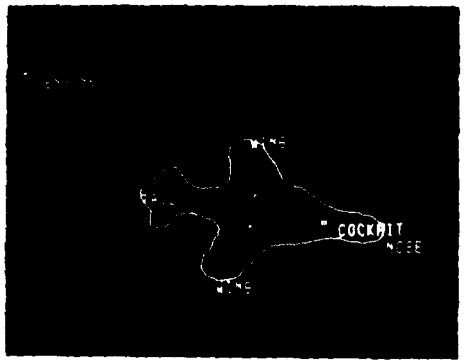


Fig 17 Harrier image analysis

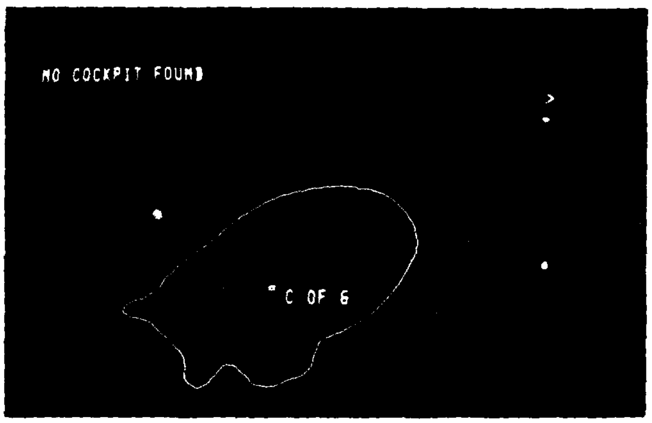


Fig 18 Airship image analysis

Fig 19 Synthetic aperture radar image of a bulk carrier

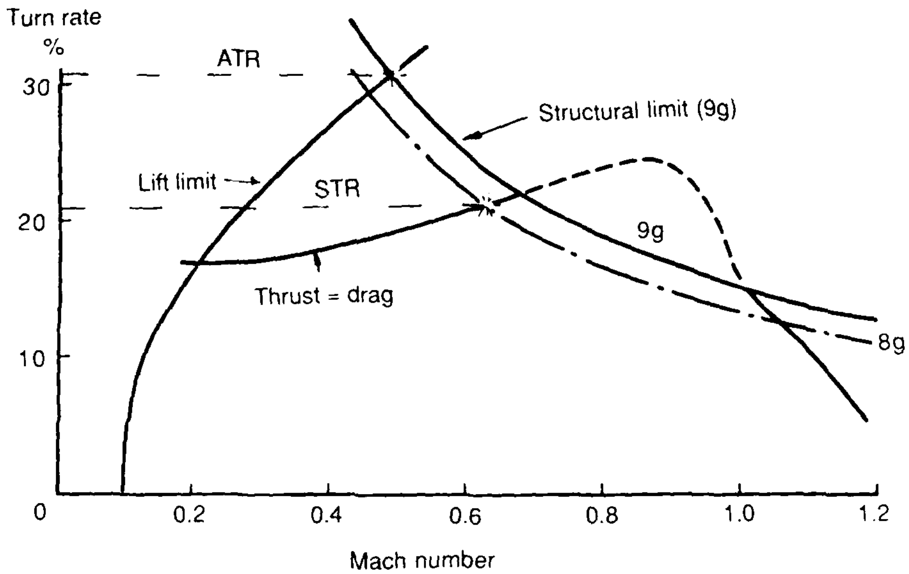


Fig 20 Aircraft manoeuvre performance at sea level

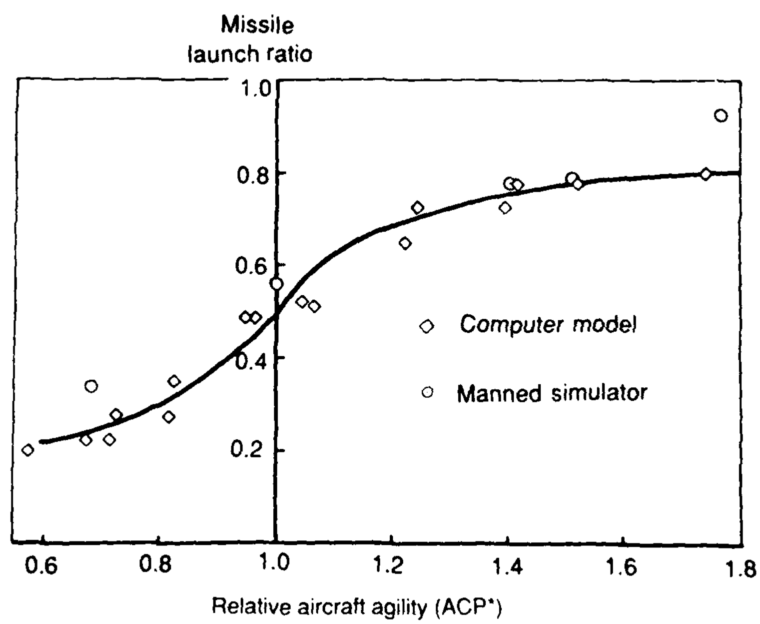


Fig 21 Correlation of close combat study results

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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

17. Abstract

After a brief summary of the history of RAE an outline is given of the Establishment's facilities, including the guided weapon ranges which are currently being modernised. The scope and rationale of its research programme are illustrated by descriptions of a number of specific items: night and all-weather operations, flight control of ASTOVL aircraft, applications of computational fluid mechanics to aircraft and gas turbines, advanced airframe materials, aim-point refinement for guided weapons, and remote sensing of the Earth's surface from space. The use of [illegible] techniques in research planning and in support of the definition of [illegible] requirements is then discussed and reference is made also to relationships with industry and to future trends in research.

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